THE EXPERIMENTAL INVESTIGATIONS OF THE BREACH IN THE HELICAL PERTURBATIONS DURING THE MAJOR DISRUPTIONS IN T-11M

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The study of the disruptive instability dynamics and origin will be one of the main way of tokamak experimental research at least for the nearest several years. The final goal of this research should be the disruption avoiding or minimization of the disruption consequences in tokamak-reactor. Previous studies of the disruptions show ([1] for example), that the more powerful plasma–wall interaction takes place in the fast phase of the major disruption (probably a result of magnetic stochastization). The reason of this phenomenon can be the fast magnetic islands reconnection through over the plasma cross-section in regions between $q(r) = m$ and $q(r) = m\pm1$. In any case for practical purposes it is important to know how uniform is the energy and particle deposition to the first wall during disruption (peaking factor problem). Obviously, it depends on symmetrical or nonsymmetrical magnetic configuration disintegrates during the disruption. The local breakage of the magnetic configuration can be possible (for example, plasma has alignment of magnetic islands X-points in the one toroidal position [2] than it looks like a local breach in initial helical MHD-perturbations).

The first description of the major disruption as the consequential development of the helical poloidal harmonics (from $m = 2$ to $m = 5$) was performed by V. Merejkin [3]. This approach has replaced the previous suggestion about dominant role of the short scale perturbations in disruption [4].

According to Merejkin we can expect, that the long scale magnetic perturbations have the spatial helical structure in disruption: $\xi(r,\theta,\varphi,t) = \xi(r)\exp(\omega t - m\theta + n\varphi)$, where r is small radius, ω is circular frequency, θ and φ are poloidal and toroidal angles, m and n are the numbers of poloidal and toroidal harmonics (modes). In this conception the particle and energy transport should be the result of magnetic islands overlapping (m with $m\pm1$), and is approximately uniform along the torus.

To test the conservation of perturbation helical symmetry during disruption we need to perform the amplitude and phase analysis of $\tilde{B}(\theta)$-signals simultaneously in several toroidal cross-sections. Two sets of poloidal magnetic probes (24 and 32 probes) separated by 40 degrees in toroidal direction was used for this purpose in T-11M ([1], R = 0.7m, a = 0.2m, J_P = 80kA, q(a) ≈ 4) to check previously observed visible helical asymmetry of the modes in major disruption [5]. According to Merejkin's scheme [3], we have performed the harmonic analysis of magnetic perturbations during minor and major disruptions with time resolution of 1 μsec for the same discharge conditions. Fig. 1 shows the result of such analysis for m = 2,3,4 (the m>4 amplitudes are small). The behavior of plasma current ΔJp/Jp and local magnetic perturbation $\tilde{B}(\theta)$ ($\tau_{integr.}$= 100 μsec) in minor and major disruption in T-11M is displayed in Fig.1a. The fast positive plasma current spike is the characteristic feature of the major disruption. Magnetic perturbations precede the start of current spike ΔJp [1,3]. Fig. 1b shows the same signals in time scale 100 μsec. The spatial analysis of poloidal harmonics (Figs.1c, 1d,1e) performed for two toroidal cross-sections (#1, #2) finds the significant toroidal difference in the behavior of low modes ($m_{\#1}$= 2, $m_{\#2}$= 2 and $m_{\#1}$= 3, $m_{\#2}$= 3). In the minor disruption and for the precursor phases the conditions of toroidal helical symmetry are accurate for all modes, but in the current spike phase it is correct only for "external" modes m≥4. We shall notice that a greater difference is observed in phase characteristics of low modes. Figs. 2a, 2b, 2c show the temporal behavior of the Δθ-phase difference between the same poloidal harmonics (m = 2,3,4). In the case of helical symmetry the amplitude and phase conservation of single m-harmonic in each cross-section will be the vector sum of all harmonics with different n and equal m. If we assume the forceless configuration of the current perturbations $\tilde{J}(\theta)$ ($\tilde{J}(\theta)$ is rigorously directed to the main magnetic field lines), we have, $q(r) = B_\varphi r / B_\theta R = m/n$.

For our experimental conditions (1 < q(r) < 4, and Δφ = 40 degrees) the different harmonics should have the Δθ difference:

$\Delta\theta=20^0 \div 40^0$ for m=2/n=1 ÷ m=2/n=2;

$\Delta\theta=13^0 \div 40^0$ for m=3/n=1 ÷ m=3/n=3;

$\Delta\theta=10^0 \div 40^0$ for m=4/n=1 ÷ m=4/n=4.

The local radial forces can move out the closed perturbation current tubes (for example, ∇P in region of magnetic islands X-points) and decrease the phase difference, but it is difficult to assume the reduction of Δθ from plus 20 to minus 17 degrees, as we can see in Fig. 2a for m = 2. The comparison of the Fig. 1 and Fig. 2 shows that the helical symmetry of magnetic perturbations conserved rather well for m = 4 (n = 1). For m = 2 and m = 3 this is not truet. We need to suppose that the current perturbations, which create the “internal” magnetic perturbations m = 2,3, cross the lines of main helical magnetic field during the major disruption. As a result, they create the local force configuration which can be the reason of local (along torus) tokamak magnetic configuration disintegration. This problem needs a further analysis. Finally, it cannot be excluded that for high level of the internal perturbations this analysis is not fully correct because we used the finite number of modes.

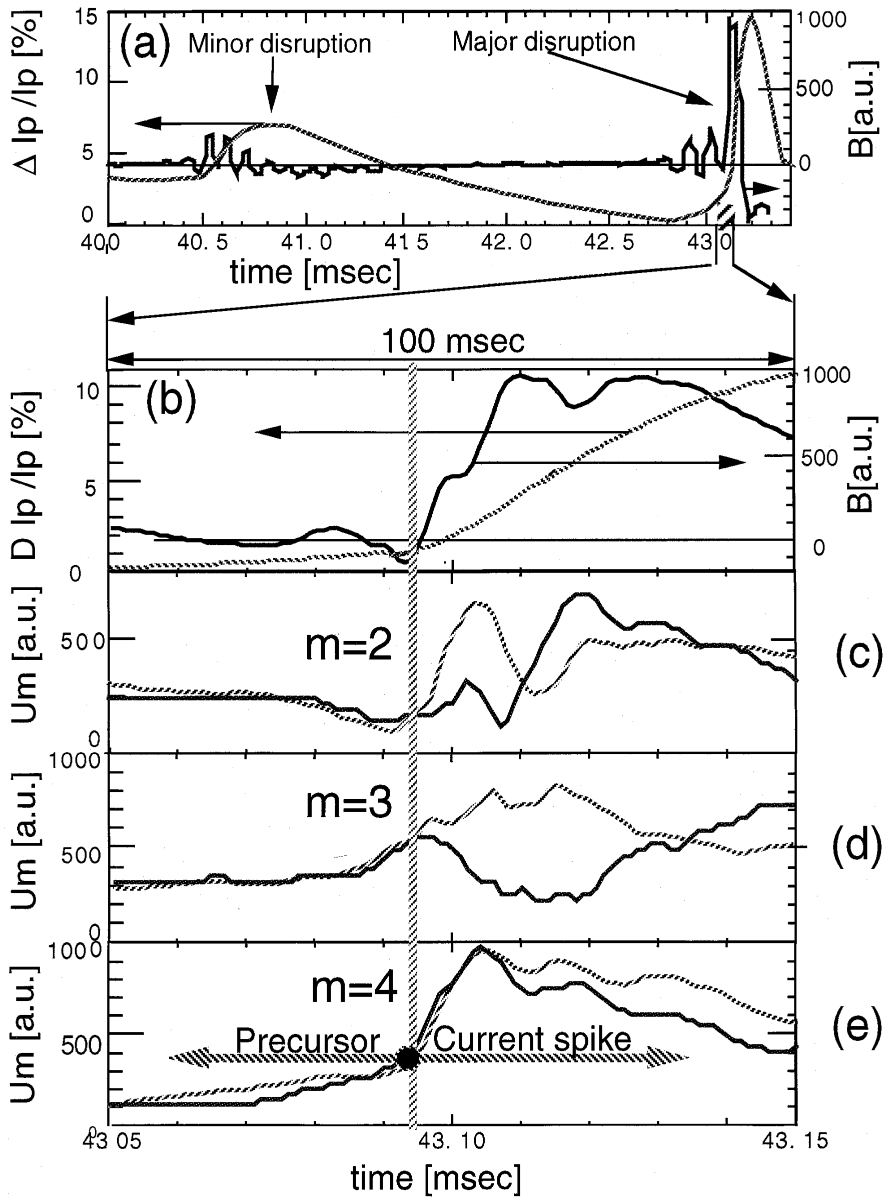

Figure 1. Behavior of the modes m = 2,3,4 in two cross-section ($\Delta\varphi = 40^{\circ}$) of the T-11M.

Conclusion

1. Simultaneous amplitude and phase analysis of the $\tilde{B}(\theta)$ poloidal magnetic perturbations

performed with high temporal and spatial resolution for two toroidal cross-sections in tokamak T-11M shows that:

a) Development of the MHD-perturbations during the minor disruption and in the precursor stage of major disruption supports the conception that the helical structure is close to the structure of main helical magnetic field (forcefree configuration).

b) In major disruption, during the positive current spike phase the helical symmetry of "internal" magnetic perturbations (m = 2,3) disappear and current perturbations should cross the main magnetic field lines (forces configuration).

2. We cannot exclude that the formation of the local force configuration during the major disruption can be the reason of local (around the torus) configuration disintegration.

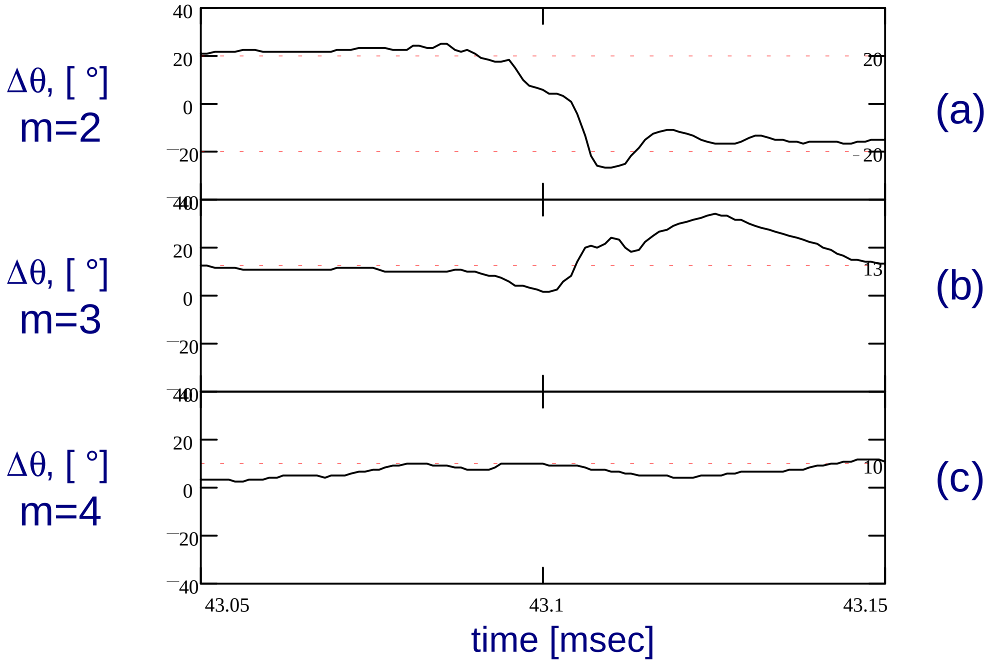

Figure 2. Δθ - phase difference between the same poloidal harmonics m = 2,3,4 in two cross-section separated by 40 degrees in the toroidal direction (tokamak T-11M).

References

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